1.7 MOSAIC VERSUS DUAL SOURCE APPROACHES FOR MODELING THE SURFACE ENERGY BALANCE OF A SEMI-ARID LAND

Boulet Gilles*, Chehbouni Abdelghani
ORSTOM/IMADES, Hermosillo, Mexico
Braud Isabelle
LTHE, Grenoble, France

1. INTRODUCTION

Accurate estimation of the components of the surface energy balance is crucial to the understanding of the interactions between hydrological cycle and climate processes at local and regional scales. This is a difficult task at any region, but the challenge is compounded in arid and semi-arid regions due to the large spatial and temporal variability of surface characteristics such as moisture, temperature, albedo, vegetation type and cover at several nested scales.

Recently, several "so-called" two-layer models (which represent the generalization of the single-source approach) have been developed to estimate local scale surface fluxes over sparsely vegetated surfaces. The key assumption behind these models is that they consider that water and heat enter or leave the atmosphere only via the canopy. However, this assumption may not always be appropriate in arid and semi-arid regions where the vegetation might be interspaced by large patches of unshaded bare soil. Under such condition, heat and mass exchanges between a part of soil surface and the atmosphere may take place with little interaction with the adjacent canopy. Therefore knowing the distribution of the vegetation within the surface is required in order to accurately represent the exchange mechanisms between heterogeneous surfaces and the atmosphere.

The objective of this study is 1- to compare the performances of two versions of a Soil Vegetation Atmosphere Transfer (SVAT) model over a non uniformly distributed vegetation in the San Pedro Basin ; the first version is the « classical » dual source (two component) model, and the second a three component model, the three components of the surface being the vegetation, the soil under-vegetation, and the unshaded bare soil. 2- to investigate which parameters values have to be artificially modified prior to the execution of the original two component version in order to compute similar fluxes as those given by the three component model.

First, the two component SVAT model and its three component version (built as an ensemble of two independent columns, one of unshaded bare soil and one of bare soil interacting with the vegetation) will be presented (section 2), as well as the experimental background (section 3). Then, some analytical comparisons will be made on the mathematics of the energy balance in both schemes (section 4), and results of the simulations will be presented in section 5.

Corresponding author address : Gilles Boulet, Laboratoire d'étude des Transferts en Hydrologie et Environnement, BP 43, F-38041, Grenoble cedex 9, France ; e-mail : Gilles.Boulet@hmg.inpg.fr

2. MODEL DESCRIPTION

A detailed description of the SiSPAT (Simple Soil-Plant-Atmosphere transfer) SVAT model can be found in Braud et al. (1995). SiSPAT is a vertical 1-D model, forced with climatic series of air temperature, humidity, wind speed, incoming solar and long-wave radiation and rainfall.

In the soil, coupled heat and mass transfer equations are solved for temperature and matric potential. They include both liquid and vapor transfers. At the soil-plant-atmosphere interface, bare soil and vegetation are considered separately in a two source model (Shuttleworth and Wallace, 1985). It provides the upper boundary conditions (matric potential and temperature) for the soil module. The incoming energy is partitioned between bare soil and vegetation through a shielding factor s_V (Taconet et al., 1986). The shielding factor σ_f is expressed as a function of the leaf area index (LAI) : $s_f = 1 - e^{-0.4LAI}$.

The vegetation is considered as semi-transparent, and multiple reflections between the soil and the canopy are allowed. In the soil, a root extraction term is included and modeled with a resistance network. The assumption that the total root-extraction is equal to the plant transpiration allows for the computation of the leaf water potential which is used to compute the stomatal resistance water stress function.

The « mosaic » or « three component » version of the model is built as an area average of two independent one dimensional columns (Figure 1), one of pure bare soil, and one of bare soil overlaid by vegetation (original « dual source », or two component model). This means that two separate solutions of the soil-plant-atmosphere interface module, and therefore two upper boundary conditions for the soil module are calculated. For the bare unshaded soil column, it is done with the help of one energy balance and one mass conservation equations, but five equations are needed for the ensemble shaded bare soil + vegetation : two for the energy balance, one for the mass conservation, and two for the sensible and latent heat flux continuity.

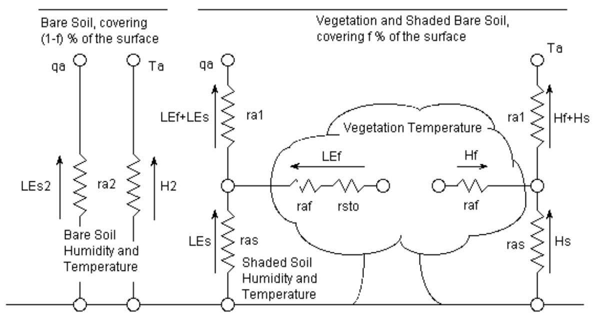

Figure 1 : Diagram for the mosaic version of SiSPAT

3 EXPERIMENTAL DATA

The SALSA multidisciplinary field campaign is conducted over the San Pedro river basin at the border between Arizona and Sonora. Fluxes and standard meteorological data, as well as soil humidity and temperature data were collected at the Zapata site (31,013° N, 110,09° W) during the summer of 1997. The surface soil texture is mainly sandy loam. Vegetation is a sparse grassland covering about 20% of the soil surface. Vegetation height is about 15 to 20 cm. The surface LAI is about 0.3 which implies that the clump LAI of the standing green part was around 1.5 (LAI_{clump}=LAI*1/f with f=0.20).

4 ANALYTICAL CONSIDERATIONS

The matching between the two- and three-component schemes is partially addressed in this section. The issue is: if the three component version represents more realistically the surface energy balance, under which assumptions can we analytically deduce « artificial » values of parameters based on the two component formalism that produce the same fluxes as the three component one ? The fluxes considered here are the net radiation, the sensible heat flux and the latent heat flux.

For the net radiation Rn, one can adjust the soil albedo α_g' in order to match both expressions of the reflected short wave radiations. Matching of the albedo expressions (right hand side: total albedo for the two component version ; left hand side : total albedo for the three component version) gives:

$$s_v' a_v + \frac{s_v'(1-s_v')^2}{1-s_v' a_v a_s'} = (1-f)a_s + f\left(s_v a_v + \frac{a_s(1-s_v)^2}{1-s_v a_v a_s}\right)$$

where α_s and α_v are the soil and vegetation albedos respectively, and σ_v and σ_v' are the shielding factors calculated with the clump LAI and surface LAI respectively. This gives a value for α_s' substantially higher than α_s. In that case, values of albedo for the two and the three components are identical. In order to compute the same net radiation with both schemes, we must match the upward longwave radiations as well. However, since surface and aerodynamic temperature values are solved differently from one scheme to the other, the difference of upward longwave radiation between both versions (the unshaded bare soil temperature being higher than the shaded one) remain unresolved, and must be explored with the model, using it as a « black box » tool.

For the sensible heat flux H, Chehbouni et al. (1997) derived an « effective » resistance from the electrical analog scheme. In a similar fashion, matching these resistances gives :

$$r_{af}' r_{as}' / (r_{af}' + r_{as}') + r_{a1}' = \frac{r_{a2}\left(r_{af} r_{as}/(r_{af}+r_{as}) + r_{a1}\right)}{f r_{2a} + (1-f)\left(r_{af} r_{as}/(r_{af}+r_{as}) + r_{a1}\right)}$$

The same type of formula can be adapted to the latent heat flux (LE) :

$$r_v' r_{as}' / (r_v' + r_{as}') + r_{a1}' = \frac{r_{a2}\left(r_v r_{as}/(r_f+r_{as}) + r_{a1}\right)}{f r_{a2} + (1-f)\left(r_v r_{as}/(r_v+r_{as}) + r_{a1}\right)}$$

where rv is the sum of the canopy aerodynamic resistance raf and the stomatal resistance rsto. In both cases (H and LE), the same problem occurs : the difference between the shaded and unshaded soil temperatures prevents us from drawing any analytical conclusion on the use of an equivalent « effective » resistance.

5 COMPUTATIONAL RESULTS

Both versions of the model have been applied with the set of measured parameters, when available, and « typical » values otherwise. They were running with a twenty days climate forcing. Then two parameters have been optimized to reproduce, with the original two component model, the fluxes as given by the three component model : soil albedo α_s' and minimum stomatal resistance r_{stmin}.

The same study has been carried out, as a reference, for the MONSOON'90 (Kustas and Goodrich, 1994) Lucky Hills site data set, whose vegetation is mainly composed of short shrubs. For this data-set, effective resistances for momentum transfer were computed using observed values of surface temperature. The ratio between the two component effective resistance and the three component one (left and right hand side of the above equation respectively) was around 0.7 at night and 1.3 around midday, leading to a slight underestimation of H if the two component version is used. For the SALSA data set, surface temperatures are not yet available, and this investigation could not be carried out.

For the MONSOON'90 data set, the mosaic version gives better estimation of both fluxes and surface temperatures (table 1) than the original version. Increasing artificially the minimum stomatal resistance (from 50 to 150 s/m) and the soil albedo (from 0 .24 to 0.31) to rather « unrealistic » values improves the estimation of the energy balance by the two component model (« modified » version). However, the resulting surface temperatures deviate considerably from observations. We must note that, in that case, the optimized albedo was even larger (0.30) than the value given by the analysis of section 4 (0.28).

Table 1: Slope/intercept of the regression of simulated vs observed fluxes for the MONSOON'90 data set (respectively).

MONSOON 1990	mosaic 3 component	original 2 component	modified 2 component
Rn	1.01 /-19	**1.07 /-15**	1.00 /-19
G	1.21 /5	1.17 /4	1.14 /3
H	1.02 /4	**0.72 /-1**	0.90 /1
LE*	0.57 /24	0.91 /27	0.70 /24
Soil T**	0.89 /1.9	0.76 /4.2	0.75 /4.3
Leaf T	1.05 /-0.4	1.12 /-1.2	**1.46 /-7**

* Despite several sensitivity tests, Observed LE was never reproduced by the mosaic version. This fact is coherent with previous MONSOON'90 validation tests.

** Temperature of the unshaded bare soil (mosaic version) or shaded soil (two component version).

For the SALSA data-set, the mosaic version did not give satisfying results, especially regarding the sensible heat flux (table 2). Several sensitivity tests have been carried out to check if slightly different values for the most sensitive parameters (mainly soil roughness length) could improve the estimation, but none of them gave satisfaction. The fact that the original version gives better results than the mosaic one can be partly explained by the small scale of heterogeneity of the Zapata site vegetation cover (the grass clump instead of the shrub).

Table 2: Slope/ intercept of the regression of simulated vs observed fluxes for the SALSA data set (respectively).

SALSA 1997	mosaic 3 component	original 2 component	modified 2 component
Rn	1.00 /-3	0.97 /-7	1.02 /-6
G at 1.5 cm	0.98 /-9	1.16 /-8	1.21 /-8
H	**1.17 /9**	0.89 /7	1.04 /9
LE*	0.88 /17	0.99 /21	0.92 /20

Indeed, splitting the surface cover in two columns that interact with the atmosphere in a quasi-independent manner is not valid at this scale of heterogeneity, and a « bulk » roughness length of one single column (intermediate between the bare soil and the vegetation roughness) is more realistic than two different roughness lengths. In other words, inter-compartment advection can no longer be neglected if the size of the unshaded soil patch interspacing the vegetation is not large enough.

For the SALSA data-set, the surface temperatures are not yet available. Consequently, the above results are only valid for the radiative and aerodynamic fluxes, and should be completed with an intercomparison of simulated and observed surface temperatures.

6 CONCLUSIONS

In this study, a three component version of a SVAT model was used to estimate the surface energy balance over a sparsely distributed semi-arid vegetation. Its performance was compared with the original two component model. In the three component version, the surface is represented by two adjacent columns : one of vegetation and its underlying bare soil, and one of open, unshaded bare soil. The results show that this representation can provide an accurate description of the energy balance comparatively to the classical dual source model if the degree of non-uniformity (i.e. the typical length scale of the patches of bare soil between the vegetation elements) is large. However, when the « sparseness index » is low, the two component model gives more accurate results. In both cases, the differences between fluxes computed by the three- and two- component versions can be greatly reduced by changing artificially albedo and minimum stomatal resistance values in the two- component model. Further study is required to determine the critical degree of sparseness above which we need to use the three component model.

7 ACKNOWLEDGEMENTS

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